REMARKS

Claims 1-7 are pending in the application. Claims 1-7 are rejected. Claim 5 is herein canceled. Claims 3, 6 and 7 are herein amended. Attached hereto is a marked-up version of the change by the current amendment, entitled "Version with Markings to Show Changes Made."

Objections to the Drawings

The drawings are objected to because the Examiner notes that Figure 12 is missing. Applicants note that there is no Figure 12, per se. Rather, Figures 12(a) and 12(b) are included in the specification.

However, Applicants note that the specification on page 8, line 18 reads, "Fig. 12 is a diagram showing crystallinity of sulfur-doped, n-type semiconductor diamond of the embodiment illustrated where (a) shows a secondary electron microscopic (SEM) image and (b) shows a reflection electron diffraction (RHEED) pattern".

Applicants submit that the Examiner may have been confused by this description of Figs. 12(a) and 12(b). Therefore, Applicants herein amend the specification to read,

"Fig. 12 (a) shows a secondary electron microscopic (SEM) image of crystallinity of sulfur-doped, n-type semiconductor diamond of the embodiment illustrated;

Fig. 12(b) shows a reflection electron diffraction (RHEED) pattern of crystallinity of sulfur-doped, n-type semiconductor diamond of the embodiment illustrated".

Applicants submit that this amendment clarifies the state of the claims.

Claim Rejection under 35 U.S.C. §112

Claim 6 recites the limitation "hydrogen plasma exposure treatment" in line 2. There is insufficient antecedent basis for this limitation in the claim. Applicants herein amend claim 6 to correct the antecedency.

Claim 7 is rejected as being indefinite for failing to particularly point out and distinctly claim the subject matter that Applicants regard as the invention. Claim 7 cites the limitation of "a substrate temperature lies in a range between 700 and 1100°C".

Applicants herein adopt the Examiners suggestion of deleting "lies in a range", so the claim reads a "a substrate temperature between 700 and 1100°C". This correction was noted and corrected in claim 5 as well.

The Examiner asserts that the broad range or limitation together with a narrow range or limitation that falls within the broad range or limitation (in the same claim) is considered indefinite. In the present instance, claim 7 recites the broad recitation a range of 700-1100°C, and the claim also recites "preferably 830°C", which is the narrower statement of the range/limitation.

Applicants herein delete the occurrence of the term "preferably 830°C" from claim 7, and add new claim 20, which recites the preferred temperature.

Claim Rejections under 35 U.S.C. §103

Claims 1-7 are rejected under 35 U.S.C. §103(a) as being unpatentable over Imai et al. (U.S. Patent 5,001,452) in view of Imai et al. (JP 01-103994), along with Jin et al. (U.S. 5,977,697).

The Examiner concludes that it would have been obvious to combine Imai et al. ('452) with Imai et al. (JP '994) to grow of crystal of diamond free of defects and having a smooth surface. The Examiner further concludes that it would have been obvious to modify the combination of Imai et al ('571) and Imai et al. (JP '994) and Jin et al. to clean the surface and remove amorphous phases, thereby improving crystallinity.

Applicants respectfully traverse this rejection, because the cited references do not teach or suggest all the limitations of the present claims.

Applicants note that to establish a *prima facie* case of obviousness, three basic criteria must be met. First, the prior art reference (or references when combined) must teach or suggest all the claim limitations. Second, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine reference teachings. Finally, there must be a reasonable expectation of success. (Manual of Patent Examining Procedure §2142). The teaching or suggestion to make the claimed combination and the reasonable expectation of success must both be found in the prior art, and not based on Applicants' disclosure.

Applicants respectfully disagree with the rejections under 35 U.S.C. §103, because at least the first basic criterion noted above does not appear to be met, i.e., not all of the limitations of the claims are taught or suggested by the cited references. Further, the Examiner's suggestion to combine the references does not appear to come from the references themselves.

Applicants note that the presently claimed step of mechanically polishing a diamond substrate to make it an inclined diamond substrate does not appear to be taught or suggested by the cited references.

Applicants note that the abstract of JP '994 teaches the step of making the substrate to have less than 8° angle to the face orientation. JP '994 does not appear to teach any desirability of an inclined substrate. Rather, it teaches making the substrate as flat as possible, but certainly less than an 8° angle.

Furthermore, Applicants note that all of the above references appear to be directed toward a substrate as flat as possible, which suggest as little inclination as possible.

Therefore, there is shown no teaching or suggestion to perform the step of mechanically polishing a diamond substrate to make it an inclined diamond substrate. Because this step does not appear to be taught or suggested by the cited references, the method claims should be not obvious over the cited references.

Furthermore, Applicants note that the Examiner has asserted that Imai ('571), Imai (JP '994), and Jin teach that the (100) plane of a diamond may incline in 8 degrees or less. The Examiner asserts that this is equivalent to the present invention, which teaches that the plane normal of the substrate may incline in 1.5-6 degrees concerning to the <100> direction in the plane which the <100> direction and the <001> direction make, or the plane which the <100> direction and the <010> direction make.

However, Applicants submit that it is clear that those are not equivalent. Applicants note that the difference in the inclination produces an n-type diamond that differs from n-type diamond of the cited references. The reason is explained below.

First, as to inclination in the present invention and inclination of the cited reference:

Applicants submit Reference Figure 1, which shows inclination of the present invention and that of the cited reference. In Reference Figure 1, the arrow shows the plane normal of (100) substrate. The plane normal of the substrate in this invention is shown in the (A) and (B) figures, and the plane normal of the cited reference is shown in the (C) figure. The plane that the <100> direction and the <101> direction of crystal axis make is shown as plane 1, and the <100> direction of crystal axis and the <001> direction f crystal axis make is shown as plane 2. The portion smeared away in gray in the figure is the possible direction of the plane normal. As shown in the (A) and (B) figures, inclination of the plane normal of this application is in the plane 1 or the plane 2, and the range of it is 1.5-6 degrees from <100> direction of crystal axis, not including 0 degrees which corresponds to that the plane normal coincides to the <100> direction of crystal axis.

On the other hand, as shown in the (C) figure, inclination of cited reference is in all planes, and the range of it is 0-8 degrees, including 0 degrees, which corresponds to that the plane normal coincides to the <100> direction of crystal axis. Therefore, as shown in the Reference Figure 1, inclination of this application differs from inclination of cited references.

In reference to the effects caused by the difference in inclination, Applicants note that by polishing the surface of the substrate within the limits of inclination in this invention, and by exposing this substrate surface to hydrogen plasma, the surface that stands in a row in the shape of a stair as shown in (b) of Fig. 1 of the present application is obtained. The step of the stair consists of (100) plane, and whose thickness is about an atomic layer, namely stepped contiguously each in the order of an atomic layer.

In the polishing that has the inclination outside the range of inclination of this application, the surface described above is not obtained.

The n-type semiconductor diamond of this invention is obtained by exposing the substrate surface that has the surface described above to the microwave plasma of the gas which consists of volatile hydrocarbon, a sulfur compound and hydrogen.

In the substrate surface which does not have the surface described above, n-type semiconductor diamond if this invention is not obtained. Incidentally, as shown in (c) of Fig. 1 in the application, even if it is the case, the coincidence of the substrate plane normal to the <100> direction of crystal axis, n-type semiconductor diamond of this invention is not obtained.

Further, with reference to the difference between the presently claimed invention and the cited references, Applicants note that when forming a p-n junction device, it is required not only being capable to obtain n-type conductivity and p-type conductivity of the semiconductor, but also crystal completeness that is enough to operate as p-n junction device.

For example, when lattice defects, such as interstitial impurities, the dislocation, vacancy, or lattice distortion exist, leak current occurs in a p-n junction device, and it becomes difficult to make it operate as a p-n junction device. However, the n-type diamond of this invention has enough characteristics for forming a p-n junction device.

That is, the sulfur atom forms single donor level 0.38 eV (refer to Fig. 6 of the specification), which means that the carbon atom of the diamond lattice is substituted completely by the sulfur atom and the sulfur atom makes no lattice defects.

Moreover, the carrier mobility exhibits 3/2nd power temperature dependency, which is the necessary feature of a semiconductor for p-n junction device (refer to Figs. 7-9 in the application). Further, it has very narrow Raman spectrum half-width (refer to Fig. 10), exciton luminescence (refer to Fig. 11), and the electron-diffraction pattern shows the Kikuchi pattern (refer to Fig. 12).

These properties all show that the interstitial impurities, the dislocations, vacancy, and crystal distortion do not exist in the n-type diamond of this invention. That is, the n-type diamond of this invention is n-type diamond with a necessary property to a p-n junction device.

The example of an actual proof from which a good p-n diode property is obtained with the n-type diamond of this invention is shown in Reference Figure 2, which is also cited in Japanese application JPA 11-174722.

The p-n diode used for this measurement was formed by using a well-known B dope p-type diamond substrate, by polishing the substrate surface following the method of this invention, that is, the plane normal of this substrate incline in the range of 1.5-6 degrees to the <100> direction in the plane that the <100> direction and the <001> direction make, or the plane that the <100> direction and the <010> direction make. By exposing this surface to hydrogen plasma, the stair-shaped surface as shown in (b) of Fig. 1 was obtained. By exposing this surface to the microwave plasma of the gas which consists of volatile hydrocarbon, a sulfur compound, and hydrogen, epitaxial growth of the sulfur dope n-type semiconductor diamond was formed.

From Figure 2, it is seen that this p-n junction device has a good rectification property in the temperature range from a room temperature to 500°C, and particularly leak current can not be seen at all in the reverse bias voltage region. On the other hand, it is only shown that the diamond in Imai ('452) exhibits n-type conductivity and the value of the carrier mobility is high.

Moreover, in column 3, lines 53-61 of Imai ('452), the text reads as follows: "Without being bounded by theory, these electrons serving as donors are believed to contribute to the n-type semiconducting properties of the diamond. In other words, S or Se introduced in the diamond as a dopant creates a donor level in the inhibition band. In certain cases, S or Se might cause a Frenkel defect (i.e., the simultaneous presence of one vacancy and one interstitial impurity atom) rather than substitution in regular carbon lattice sites, and this may also serve to create donor levels."

Specifically, Applicants note that, "the diamond which has n-type conductivity" is indicated by the cited reference Imai (;452) and "n-type diamond applicable to a p-n junction device" is not indicated.

That is, if donor is based on impurities between lattice sites and vacancy, even if n-type conductivity is obtainable, but it is difficult to operate as a p-n junction device because of the leak current at the p-n junction based on such lattice defects.

In conclusion, Applicants assert that the inclination of the substrate surface in the present invention differs from it of the cited reference.

For at least the above reasons, Applicants submit that the present claims, as herein amended, overcome the rejections and define patentable subject matter. Withdrawal of the rejections and passage of the claims to issue are earnestly requested.

If the Examiner believes that this application is not now in condition for allowance, the Examiner is requested to contact Applicants' undersigned attorney at the telephone number indicated below to arrange for an interview to expedite the disposition of this case.

In the event that this paper is not timely filed, Applicants respectfully petition for an appropriate extension of time. Please charge any fees for such an extension of time and any other fees that may be due with respect to this paper to Deposit Account No. 01-2340.

Respectfully submitted,

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PATENT TRADEMARK OFFICE

Enclosures: Version with markings to show changes made
Reference Figure 1 and Reference Figure 2

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VERSION WITH MARKINGS TO SHOW CHANGES MADE

IN THE SPECIFICATION:

Please amend the paragraph beginning on page 8, line 18 as follows:

Fig. ~~12 is a diagram showing crystallinity of sulfur-doped, n-type semiconductor diamond of the embodiment illustrated where (a) shows a secondary electron microscopic (SEM) image and (b) shows a reflection electron diffraction (RHEED) pattern~~

12 (a) shows a secondary electron microscopic (SEM) image of crystallinity of sulfur-doped, n-type semiconductor diamond of the embodiment illustrated;

Fig. 12(b) shows a reflection electron diffraction (RHEED) pattern of crystallinity of sulfur-doped, n-type semiconductor diamond of the embodiment illustrated ; and

IN THE CLAIMS:

Please amend claims 3, 6 and 7 as follows:

3. (Twice Amended) A method of making an n-type semiconductor diamond, characterized in that it comprises:

mechanically polishing a diamond substrate to make it in an inclined diamond substrate, which is formed by mechanically polishing a diamond (100) face oriented substrate so that its face normal is inclined at an angle between 1.5 and 6 degrees with respect to its <100> direction in a plane made by either its <100> and <010> directions or its <100> and <001> directions;

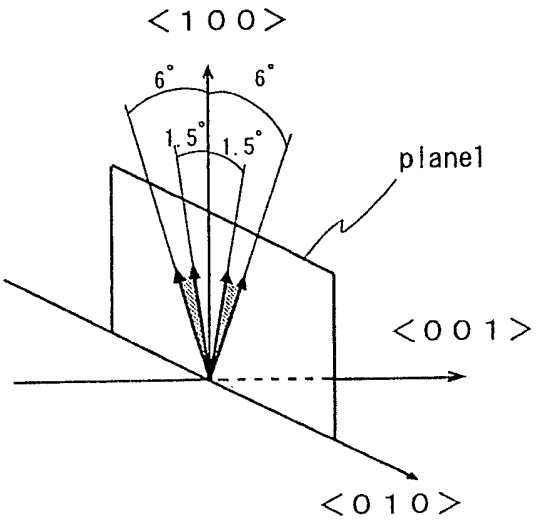
subjecting a surface of said inclined diamond substrate to a smoothening treatment make it even:

exciting a raw material gas made of a volatile hydrocarbon compound, a sulfur compound and a hydrogen gas by a microwave plasma while maintaining at a given temperature said substrate surface smoothened as aforesaid to cause n-type semiconductor diamond to grow epitaxially on said smoothened substrate.

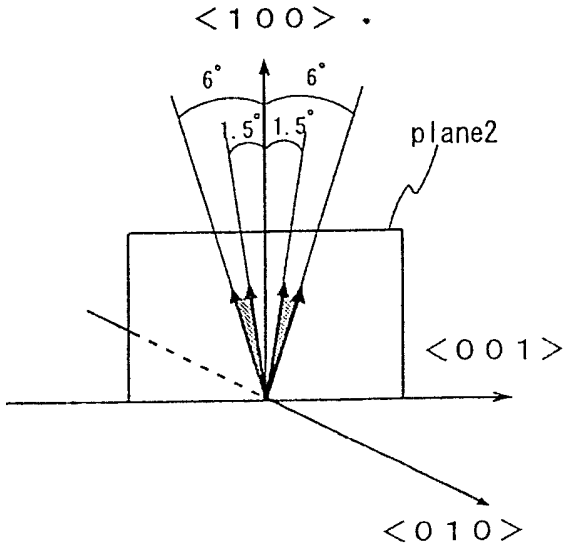
6. (Twice Amended) A method of making an n-type semiconductor diamond as set forth in claim 3, characterized in that said ~~hydrogen plasma exposure~~ smoothening treatment comprises a treatment of exposing said inclined substrate to the hydrogen plasma of a hydrogen pressure of 10 to 50 Torr and a microwave output of 200 to 1200 W at a substrate temperature of 700 to 1200 °C for a period of 0.5 hours to 5 hours, thereby to make even said substrate surface to consist of steps each in the order of an atomic layer.

7. (Twice Amended) A method of making an n-type semiconductor diamond as set forth in claim 3, characterized in that said given substrate temperature ~~lies in a range~~ is between 700 and 1100°C ~~preferably at 830°C~~.

Reference Figure1



(A)



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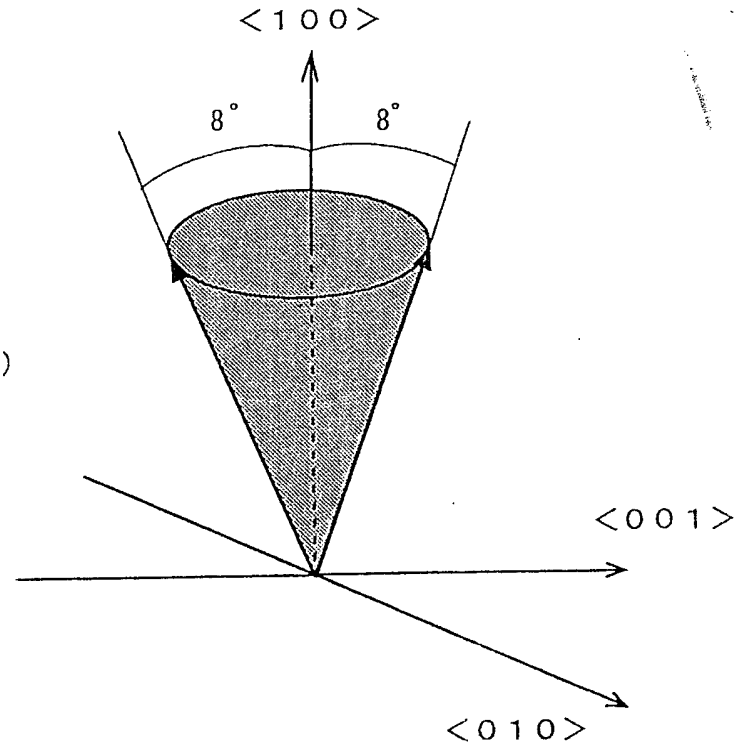

(C)

Reference Figure2